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criticism is to be made of the training that economic zoologists are receiving in our institutions it is that sufficient stress is not laid upon the necessity of learning the methods of field work. A young man coming from a university or an agricultural college knowing his insects well and well fitted to teach, is at a great disadvantage in going into practical work if he has had no field experience, and also if he does not understand agriculture, horticulture and the most important art of meeting and handling men.

It will appear from what has been said that the Massachusetts Agricultural College has borne her full share, and the Massachusetts Agricultural College in this connection means Professor Charles H. Fernald, later with his son Henry. He came here in 1886, just before the founding of the agricultural experiment stations. His published works, both in purely scientific and economic directions, have stamped him as of the first rank. His work in connection with the magnificent efforts of the state of Massachusetts to control the gipsy moth and the brown-tail moth has been of the soundest character. The affection and respect shown for him by his students is indicated almost daily by those who have come to Washington, and is easily understood by one who, like myself, has been more or less closely associated with him for thirty years. I shall never forget the summer of 1880, when he and Mrs. Fernald spent some time in Washington working with Professor Comstock, who was at that time chief of the Division of Entomology, I myself being his assistant. Professor Fernald was a constant inspiration and he was also a constant delight on account of his overflowing humor. At that time pedlars and mendicants of different kinds were allowed access to the rooms, and it was a standing joke of the professor's, when the door opened and one of these men came in, to jump to his feet, to appear to recognize him, shake his hand cordially, ask after his wife and children and the old folks at home, which almost invariably so confused the incomer that he turned around abruptly and left the room.

I understand that he is to retire now, I know of no one who has made quite so good a record, viewed from every point. A number of years ago I was riding with him along a country road in eastern Massachusetts, and he said to me, "Howard, I have been thinking about myself and of the little I have done, and I wonder whether after I shall have gone people will think of me as a systematic entomologist or rather as an economic entomologist." And I replied instantly, "You forget probably the biggest work you have done and the best work, and that is as a teacher." And is it not true? The memory of Professor Fernald will live after he goes, both as a systematist and as a strong economic entomologist, but, greater than either, as a teacher; and this building will be a visible monument to his work as long as it shall stand. May he live many more years to know and to enjoy the reputations which are being made and which shall surely continue to be made by the men he has taught.

L. O. HOWARD
U. S. DEPARTMENT OF AGRICULTURE

THE STATUS OF MODERN METEOROLOGY

INTRODUCTION

I AM transferring my work in meteorology from the U. S. Weather Bureau to other countries, after a continuous service for the government of twenty-one years, two in the Nautical Almanac and nineteen in the Weather Bureau, for reasons not relating to my official or professional duties. During this time numerous more or less detached researches have been published,

and this seems to be a good opportunity to make some remarks regarding the progress of meteorology in the past twenty years, and some comments on the present status of the problems connecting the atmospheres of the sun and the earth. While an assistant in the National Observatory, Cordoba, Argentine Republic, the Director, Dr. B. A. Gould, who established the Meteorological Office as well as the Astronomical Observatory in that country, was wont to say that he felt confident that the weather changes as observed synchronized closely with the variations in the numbers of the sun spots. It has since then been shown that Cordoba is peculiarly well situated in the midst of the high pressure belt of the southern hemisphere, to bring out this parallelism, because of its freedom from local cyclonic disturbances. Many researches, such as those by Balfour Stewart, Brückner, and others, along this line, indicated that such synchronism was real, but that the details of the phenomena are exceedingly complicated. Indeed, the fundamental question is, whether the weather variations in the earth's atmosphere admit of a further classification, by correlating them with the laws of physical processes depending upon the several types of transformed solar radiation, as heat, electricity, magnetism, pressure and density. If such a synchronous connection can ever be established in the interest of annual or seasonal forecasting, the advantage to public utilities is evidently such as to justify all reasonable efforts to secure it.

THE GENERAL PROBLEMS

The atmosphere of the earth is the seat of many physical forces in mutual interaction, *absorption and radiation* of solar energy, the transformation of this energy into *heat* and the *circulation* of masses of different densities under the force of gravitation on the rotating globe, the further transformation of solar energy into *electric* and *magnetic forces* and the other minor forms. This implies the application of the theorems of thermodynamics, hydrodynamics and electromagnetism in an endless complexity, and requires special researches and studies on a large scale. Except for recent work with balloons and kites on temperatures, vapor pressures and wind vectors, the observations of meteorology have been limited to the surface strata of the atmosphere, so that much inference and extrapolation was inevitable. Furthermore, the observations made at the numerous stations in various latitudes and longitudes have not been homogeneous, on account of the incessant changes in the location of the barometers, the thermometers, the anemometers, and other instruments, with the growth of modern cities and for commercial conveniences. All meteorological observation stations should be removed from the cities and placed in an environment that will have the same exposures for a century, while the business office for the convenience of the public is placed in the town. Finally, the theoretical science of meteorology made a bad start with its literature. The first applications of thermodynamics to hydrodynamics, the early theories of the general circulation and the formation of storms in cyclones and anticyclones, have been proved entirely inadequate and misleading. In some aspects the theory of general meteorology has been revolutionized in the past twenty years, and the rebuilding process is in operation, but the hydrodynamic problems are so difficult that progress is slow. The observations are gradually being reduced to homogeneous series, and many students are now attracted to one problem or another all over the world.

Homogeneous Observations.—The gen-

eral problem indicated can be approached in two ways, (1) the method of analytical theorems checked by a comparatively few observations; (2) the method of numerous homogeneous observations leading up to general theories. The earlier researches in meteorology, as a rule, pursued the former plan, and the result was in some cases solutions not applicable to nature. My own judgment favored the second and more laborious system as probably leading to better results in the long run. This opinion was based upon five years' experience with Dr. B. A. Gould at the Argentine observatory in stellar astronomy, and three years with Professor Simon Newcomb in connection with his Planetary Tables. These masters in science always prepared extensive observational data before proceeding to definitive discussions. Accordingly, in view of the chaotic condition of the records of data in the United States, due to changes of the local hours of observing, changes of place of the station instruments, lack of uniformity in the methods of reduction, it was necessary to devote several arduous years to the mere routine work of overhauling the original observations. This included the readjustment and discussion of the following data: (1) The magnetic and the electrical data at 30 stations in all parts of the world; (2) the cloud observations for wind vectors at several stations in the United States and the West Indies; (3) the barometric system of the United States; (4) the temperatures and vapor pressures of the United States; (5) the precipitation records for climatology; (6) numerous observations on evaporation in all parts of the United States. In consequence of this work the Weather Bureau now possesses a fundamental barometric system, upon which all forecasting since 1900 has been based, being homogeneous long-record monthly and annual values of pressure for about 200 stations with normals, 1873–1910, to which the pressure variations due to atmospheric circulation can be referred. There is, also, a homogeneous system of temperatures and vapor pressures, with 33-year normals for more than 100 stations, on which the departures in temperature due to the action of solar rediation on the circulation can be computed, and these have been made the basis of the entire climatological system of the United States. The summary of the precipitation records for several hundred stations, in 106 sections, is nearly finished, and these data furnish the basis for studies by engineers interested in water resources as applied to power and irrigation. A report on the subject of practical evaporation is now ready for the press, and covers a large amount of new matter of no little interest and importance. The cloud observations have revolutionized the theory of circulation, and the new relations discovered between the radiation of solar energy and transported heat by circulation have opened a large field for important progress. The magnetic terrestrial field was broken up into its components, (1) normal field, (2) diurnal disturbing field, (3) meridional deflecting field, (4) the field of perturbations and the relations between these fields and the corresponding currents of ions in the atmosphere, constitutes a most interesting part of the subject of the transformation of the absorbed radiant solar energy in the earth's atmosphere. Simultaneously with the revision of the observations, we have pursued extensive studies in hydrodynamics as related to circulation, in thermodynamics as connected with the causes of circulation, and in electricity and magnetism as related to radiation. The recent advances in this last subject by Heaviside, Hertz, Lorentz, Thomson and others, and

the growing interest in the subject is attested in nearly every mail by the arrival of important and valuable papers in these subjects. The ionization of the atmosphere and its consequences in a circulating medium form an inexhaustible field for valuable investigations.

The General Circulation of the Atmosphere.—These observations have been the means of subjecting to critical examination the theoretical researches of Farrel and of Oberbeck on the general circulation with the result that they are distinctly defective. This circulation is not so simple as was assumed in the elementary canal theory upon which their integrations were based, and, unfortunately, the actual circulation is too complex to admit of any simple hydrodynamic treatment. The canal theory assumes a simple overflow from the equator to the poles in the upper levels, with return underflow towards the equator in the lower levels. Our cloud work first proved that there is an interflow in all levels from the ground upwards, being a maximum in the 2-mile level, by which warm currents from the south interpenetrate cold currents from the north, and under the force of gravity set up a mixing circulation which produces cyclones and anticyclones. These southerly warm currents in the lower levels were called "leakage" currents, and their function was to break up the high pressure belt into large centers of action, around which the interchange of heat goes on rather than above and below an assumed neutral plane of motion.

At the same time the source of the heat energy that drives cyclonic storms, hurricanes and tornadoes was shifted from the latent heat of condensing water vapor, as assumed by Espy and advocated by Farrel and Abbe, to the heated masses of air whose temperature has been raised primarily in the tropics by solar radiation. Masses of air of different temperatures have their pressure-levels shifted in such a way that the force of gravitation tends to produce nearly horizontal currents, which sustain the mechanical interflow of cold and warm masses in a mixing circulation that gradually tears them to pieces, and reduces the disturbed temperatures to the normal values of their locality. My study of the distribution of temperatures between the equator and the poles in all latitudes, between the surface and 16,000 meters in elevation, has resulted in a very different picture from that heretofore presented. It has been assumed that the maximum temperatures in the levels 1,000–10,000 meters is over the equator, but I find that it is latitudes $+33°$ and $-33°$ approximately, in the high pressure belt, and that there is a distinct depression of temperature over the tropics, with a maximum at the 2-mile level. This is the only distribution of heat in harmony with the known velocities in the general circulation. Thus, the depression of temperature in the tropics is due to vertical adiabatic circulation, and the maximum in the high pressure belt is due to the downward settling of air from the higher levels, so that the real canal circulation is chiefly confined to latitudes within 50 degrees of the equator. The mechanical equations of motion require an increase in temperature from the equator towards the high pressure belt, in order to produce the westward drift and trade winds of the tropics; there must be a decrease of temperature from this maximum towards the poles to produce the eastward drift in the temperate and polar zones. The velocity of circulation is proportional to this change of temperature gradient on a given level, and hence there is maximum westward component in the 2-mile level over the tropics, especially near the high pressure

belt, and an increasing eastward drift from the surface upwards in the temperate zones to about 13,000 meters, where it begins to fall off at the isothermal level.

The Consequences of this Distribution of Temperatures in the Atmosphere.—(1) Any increase in pressure in one locality is compensated by a corresponding decrease in another locality, in order that the total pressure of the atmosphere may remain a constant. I have shown that an increase in solar radiation is attended in general by an increase of pressure in the hemisphere whose focus is the Indian Ocean, but a decrease of pressure in the American continent. (2) An increase of solar radiation means an increase of temperature throughout the tropics, and an increase in the westward drift, but a decrease of temperature in the temperate zones with an increase in the eastward drift. This strengthening of the two branches of the hemispherical torque, with opposite temperatures at the surface from the increase in the energy of the solar radiation is essential in order to preserve the constant rotation of the earth on its axis, which is observed by astronomical methods to be the fact. This necessary inversion of pressure and temperature in the several parts of the earth's atmosphere, due to the same external change in heat energy from the sun, not only reconciles a number of conflicting researches on isolated phenomena, but it tends to classify a vast number of interrelated but apparently irreconcilable facts referred to the old canal theory.

The Local Circulations in the Atmosphere.—The early theoretical studies on cyclones and anti-cyclones proceeded on the unnecessary supposition that these circulations are warm-centered or cold-centered about the axis of gyration. The arguments for this theory were based upon the easy solutions of the equations of motion, wherein Farrel assumed one and the European meteorologists another possible solution. The observed facts by means of kites and balloons do not justify such distributions of temperature about an axis, but rather such temperatures as would place the centers of gyration near the borders of the warm and cold interflowing currents just described. The hydrodynamic and the thermodynamic relations in this case become excessively complicated in the case of cyclones, which are really very irregular circulating structures, though hurricanes and tornadoes conform closely to simple vortices.

Solar Radiation and Terrestrial Fields of Heat, Magnetic and Electric Energy.—I became convinced, from a study of Maxwell's "Electricity and Magnetism," in 1889, that the most probable explanation of the outstanding problems in terrestrial magnetism and electricity would be found in the transformations of the electromagnetic energy of solar radiation in the earth's atmosphere. At that time the only known type of motion was to be found in the kinetic theory of gases, and these two systems were not very readily harmonized. The discovery of ionization, and the fact of electrons in motion in the air, accounting for induced magnetic fields and conductivity due to moving electric charges, put the entire subject on a new basis of thought. This atmospheric ionization was caused either by the transformation of the very short wave rays from the sun, or possibly by cathode corpuscles in bombardment from the sun to the planet, in the *high levels* where low densities prevail in the gases; or, else, by friction electricity generated among the molecules, dust, vapor, water and ice particles in the lower atmosphere near the surface in the *low levels;* or, finally, by radioactive radiations and emanations from the body of the earth

itself. Such were the successive inferences of the theory of electrons by ionization as later developed, though not known in 1891, when my work in that subject began. As an attack upon the problem, the observed magnetic field of the earth was subdivided into a normal field and the several deflecting magnetic fields mentioned above, the vectors being expressed in appropriate rectangular and polar coordinates. These several fields, (1) diurnal, (2) meridional, (3) perturbation, were built up by computation over the entire earth, and they form the systems of magnetic component fields to be accounted for by superposed magnetic systems, or by systems of induced currents of electric ions in motion. The formulas pertaining to this subject, especially from O. Heaviside's papers, were assembled in 1900 for use by meteorologists. The beautiful lectures on the theory of electrons, by H. A. Lorentz, 1909, will guide the reader much more fully in all these interrelated subjects. My 36-inch model of the *diurnal magnetic deflecting field* exhibited a very complex series of vectors of three types, which have the special characteristic that they are intimately associated with the *diurnal convection* of the atmosphere, and the temperatures, vapor pressures, barometric pressures and wind velocities. Now, this *diurnal convection is confined to a stratum only one or two miles thick, and therefore the magnetic vectors must be caused by the movement of the electric ions in the lower and not in the higher strata of the atmosphere,* so that this magnetic field can be caused only indirectly by the incoming radiation, that is, by the motion of the ions in low-level convection currents. It is quite probable that this lower field of electricity comes from the radioactive processes in the ground, but the stream lines of + ions in the lower strata can readily be drawn from an inspection of the magnetic vectors, whatever their physical origin. Eliminating the normal and the diurnal magnetic fields, there remains the second or *meridional field* which consists of vectors nearly perpendicular to the normal lines of magnetic force around the earth and lying closely in the planes of the magnetic meridians. These vectors form the picture of a permeable shell lying in an external field of magnetic force, and they slowly surge back and forth as a reversing system every few days, southward and northward, as if the electric currents made circuits in the air along the lines of magnetic force, high over the equator and returning as ground currents through the earth's outer layers. On collecting such vectors at stations in all parts of the earth in long tables, it was seen that the reversals had a periodic action easy to detect and mark off by dates. A least square solution gave the period 26.68 days, and thus associated it with the observed synodic rotation at the equator of the sun. At that time the commonly accepted synodic period was assumed to be about 26.00 days, derived from least square solutions on auroras, thunderstorms and magnetic fields, and therefore not in harmony with current opinions. The recent spectroscopic work of the Mt. Wilson observatory, however, fixes the equatorial period of rotation at the level of the photosphere as 26.70 days with a smaller period in higher levels of the sun's atmosphere. We infer that the mixed radiation from the sun should be sorted out by elevations, and by latitudes, as well as by longitudes, in order to complete the solution of this problem. This meridional magnetic field at the earth carries one inference with it. If the normal terrestrial magnetic field is equivalent to a system of east-west electric currents, then this disturbing field can not be accounted for by strengthening and weak-

ening these east-west currents, because the deflecting field is at right angles to the normal field, and requires north-south currents. It may be generated by the transformation of incoming solar radiation in the *outer layers* of the atmosphere, where the short waves of the spectrum are actually depleted, so that after formation the ions travel along the lines of normal magnetic force, revealing their presence in the auroras, and the slow surging of the meridional field of magnetic force. It seems to me doubtful whether this field is due to any corpuscular action bombarded from the sun, and it is more probably due to short wave transformation. The third or *perturbation* magnetic field is much more irregular in its vectors, and it may show evidences of the same forces that produce the meridional and the diurnal fields as well as some other irregular vectors. This field is more probably due to the bombardment by the solar corpuscles, being spasmodic and irregular as to period and energy. In view of the configuration and persistent periodic action of the meridional field just described, there was little else to do in 1893, before the discovery of ions, than assume the fact that the sun constitutes a huge spherical rotating magnet carrying an unequal field, due to its internal currents of polarization or fixed internal magnetic masses. My studies on the structure of the sun's coronas during the time of minimum solar activity strongly suggested this view, and especially the apparently fixed positions of certain coronal poles tended to confirm it. The objection that the sun could not be a magnetized body on account of its heat did not seem very important, because the earth is evidently hot and at the same time the seat of a permanent magnetic field. The recent discoveries of the Zeeman effect, and its presence in the sun spots, seems to put that objection out of court. The only problem now is properly to apportion the electric and magnetic parts in the solar and the terrestrial fields between the variable magnetic and electromagnetic fields which transport the energy of the sun to the earth.

Solar Synchronism and Weather Forecasting.—The revised homogeneous observations of pressure, density of vapor, temperature and magnetic field, besides providing normals for climatology and daily forecasting, afford the basis for the study of solar synchronism and long range forecasting. It has been shown already that the entire weather system of the United States systematically varies with the frequency of the solar prominences and sunspots, and with the terrestrial magnetic field. The storm tracks go to lower latitudes with the increase of solar action, the movement of the eastward drift is greater, the temperatures of the United States are lower, and the barometric pressures are higher. This is based upon 481 charts of temperature, each containing the variations of temperature from the normal, one for each month, 1873 to 1910; upon a long series of pressure charts, and upon numerous other compilations of available data. The reversal of temperatures and the increase in the velocity of the eastward drift compensates for the increase of heat energy in the tropics. Similar studies were extended to the entire earth with the result that the synchronism is everywhere, but the details are complicated. As matters stand it is entirely proper to undertake annual forecasts of the type of the coming year, whether cooler or warmer than the normal, provided suitable observations of the outgoing solar energy can be secured up to date for immediate use. The sun spots are too sluggish a measure of solar energy to be of much value; the

prominences are taken only on the edge of the disk; but similar phenomena over the entire face of the sun should be studied systematically every day at enough observatories to escape terrestrial cloudiness; direct radiation measures are still too encumbered with meteorological conditions not fully eliminated, as vapor contents and dust in the upper levels, and transported heat in all levels, to be of primary value at present; the indirect measures of the solar radiation through the magnetic field, whereby the amplitudes change with the variable solar energy, promise the most simple and effective method of observation, as soon as the subject of ionization can be more fully developed in the earth's atmosphere; the temperature, pressure and wind effects at different localities must be studied by practical forecasters, who fully understand this complex train of causes and effects. It may be stated in passing that no important improvements have been made in daily forecasting for 30 years, and the same methods continue in vogue. A change in the scale of verifications, a more or less flexible margin of allowances for errors and successes, present different percentage figures for comparison, but on reduction to the same scale there has been no improvement for many years. We prepared tables for constructing daily pressure charts on the sea level, the 3,500-foot level, and the 10,000-foot level and the mutual relations of the three respective systems of isobars are exceedingly instructive and suggestive. The trend of the upper isobars shows the coming course of the storm tracks in a remarkable manner, and the closed isobars of sea level are usually entirely drawn out on the 2-mile level. Similarly, it is possible to prepare approximate isotherms on these two upper levels, after suitable preliminary studies have been made, and the close relations of these isobars and isotherm upper level charts to the areas of precipitation already studied in part will form the only possible basis for an improved method of forecasting.

The Circulation of the Solar Mass.—The model of the circulation of the earth's atmosphere is the proper analogue for the analysis of the circulation of the matter constituting the body of the sun, if the apparent difficulties in the way of securing the thermodynamic constants in the general equations of motion can be overcome. It is quite evident that the solar circulation is an obverse picture of the terrestrial circulation. If the maximum temperatures in the earth's atmosphere occur in middle latitudes, on the sun the maximum temperatures are probably over the equator and over the poles with a minimum near the sun spot belts. If in the earth's atmosphere the westward drift is in the tropics, in that of the sun it is in the polar regions; if in the earth's atmosphere the eastward drift is in the temperate zones, in the sun's atmosphere it is in the equatorial regions. It will require much labor to work out the problem which is thus stated, but conforming to the probable action of the general equations of motion. It is my purpose to pursue these higher problems in solar physics so far as conditions permit me to do so.

Frank H. Bigelow

Washington, D. C.,
August, 1910

A Zoological Laboratory at Montego Bay, Jamaica, B. W. I.

When in 1891 Professor W. K. Brooks removed the zoological laboratory of the Johns Hopkins University to Port Henderson, near Kingston, Jamaica, he deputed the present writer to visit all the other sites on the coast in search of the best.